

CRYSTALLINE AND CRYSTALLOIDAL SUBSTANCES AND THEIR  
RELATION TO PLANT STRUCTURE.

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Nägeli and Schwendener,<sup>1</sup> in the preface to their chapter on morphology, give us probably the most comprehensive idea of the scope of the subject. They say: "Zur Morphologie im weiteren Sinne des Wortes gehört die ganze Lehre vom Aufbau der Organismen aus den Elementen, woraus sie bestehen—von den Micellen, welche die Bausteine der Zellen bilden, bis hinauf zu den Einheiten der höchsten und letzten Ordnung, welche den vielfach gegliederten Bau der höhern Gewächse zusammensetzen. Die Morphologie hat zu ermitteln, unter welchen bestimmten Form— und Lagerungsverhältnissen die Micellen und Micellarschichten sich vereinigen, um die Zelle und deren Theile zu bilden und während des Wachstums weiter aufzubauen; sie hat hierauf die Zelle als gegeben zu betrachten und zu untersuchen nach welchen Gesetzen die Vermehrung derselben erfolgt, wie gleichsam Zelle auf Zelle gesetzt wird, um die grossen Complexe zu bilden, die wir als Organe kennen; sie hat ferner die Differenzierungen zu verfolgen, welche in solchen Zellencomplexen nachträglich stattfinden, und endlich auch die Entwicklung neuer Organe aus schon vorhandenen, sowie die Natur und Stellungsverhältnisse derselben in Betracht zu ziehen."

As a result of having given considerable attention to what might be termed the morphology of plant constituents and having made a number of observations while trying to produce artificially from chemical solutions crystalline and crystalloidal substances resembling those formed naturally in the plant, such as calcium salts, inulin, hesperidin, etc., a number of questions have arisen in the author's mind concerning morphological development which are set forth in this paper.

Sphere-crystals are spherical aggregates of crystals with sharp

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<sup>1</sup> *Das Mikroskop*, von Carl Nägeli und S. Schwendener. Zweite Auflage. Leipzig: William Engelmann, 1877, p. 532.

angular contours which are made up of but one substance, the molecule of which is simple, or at least not very complex. This class includes carbon compounds as well as inorganic substances. Of these may be mentioned calcium phosphate, calcium carbonate, calcium oxalate, amygdalin, strychnine, berberine, etc. Some of these compounds are soluble in water while others are not, hence we may say that there are both soluble and insoluble sphere-crystals. As examples of the former may be mentioned the glucosides and alkaloidal salts, while as examples of the latter we have calcium phosphate and oxalate, the alkaloids, etc.

The spherites resemble somewhat the sphere-crystals, but are distinguished from them by the fact that they have a more complex composition and the individual crystals have either a somewhat rounded outline or are imbedded in colloidal substances in which the crystalline or crystalloidal character is more or less obscured and hence with difficulty discerned.

The spherites also admit of a classification into soluble and insoluble bodies. The soluble spherites, or those directly soluble in water, include hesperidin, inulin and allied carbohydrates, and their crystalline character is most apparent when the specimens are dehydrated with alcohol.

The insoluble spherites are not directly soluble in water, but may be rendered so by treatment with certain reagents. These include starch and the fundamental substances entering into the composition of the cell-wall. The spherite character of these substances is not at once apparent, but can be demonstrated by the use of reagents which cause a swelling of the substances in the starch-grain or in the cell-wall. In a paper<sup>2</sup> communicated to the Society

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<sup>2</sup> See also *Journal of American Chemical Society*, 1899, p. 650, and *American Journal of Pharmacy*, 1899, p. 174. The following are the reagents that were used:

- (1) Chloral iodine + iodine solution; of each 5 parts.
  - (2) Chlor-zinc-iodide solution.
  - (3) Chromic acid solution (15 per cent.).
  - (4) Calcium nitrate solution (30 per cent.).
  - (5) Chloral solution (saturated), water and glycerin; of each 5. parts.
- To this solution as much iodine is added as the solution will take up.
- (6) Saliva.
  - (7) Silver nitrate (2 per cent.).
  - (8) Sulphuric acid (C. P. acid 90 parts and water 10 parts).
  - (9) Taka-diastrase (saturated solution).
  - (10) Sodium acetate solution (50 per cent.).
  - (11) Potassium hydrate solution ( $\frac{1}{10}$  of 1 per cent.).

of Plant Morphology and Physiology, 1899, the author enumerated the substances which could be used to bring out the spherite structure in the starch-grain. The same kind of reagents, but in stronger solutions, may be used to bring out the spherite structure in the wall of thickened parenchyma cells, as endosperm, or lignified cells, as stone cells. In cases where the cell-wall has been metamorphosed into mucilage, simple treatment with water, as has also been shown with the starch-grain, is sufficient to bring out the structure.<sup>3</sup> The reason that this structure is not apparent under natural conditions is because the refractive properties of the crystalloidal substance so nearly resembles that of the associated colloid. The use of certain reagents, however, which are more or less penetrating in their action, cause an imbibition of water by the colloidal portions with consequent swelling of the grain, or cell-wall, and a contrast in refractive power with the more insoluble and hence unaffected crystalloidal substances.

Sphere-crystals are further distinguished from spherites in that the latter are capable of taking up or holding certain coloring principles, as safranin, gentian violet, etc. It is questionable, however, if the crystalloids contained in the spherite take up the coloring matters, it being probable that the colloid associated with the crystalloid is the portion that is colored, as I have already shown in my studies on the structure of the starch-grain.

In the cell-wall the crystalloids occur in very close radial and tangential rows and constitute by far the greater proportion of the wall. In the starch-grain, on the other hand, there is apparently a greater preponderance of colloidal matter which takes up certain stains. This layering, which is well marked in the starch-grain, is scarcely distinguishable in the cell-wall. The reason that it is not so well marked in the cell-wall is because of the difference in amount of the crystalloidal and colloidal substances, the close arrangement of the crystalloids and also the difficulty of obtaining uniform microscopical sections, as can be readily obtained with the starch-grain.

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(12) Potassium nitrate solution (saturated).

(13) Tannin solution.

(14) Potassium phosphate solution (saturated).

(15) Hydrochloric acid (5 per cent.).

(16) Water between the temperatures of 50° C. and 70° C.

<sup>3</sup> This would tend to show that the crystalline structure is not due to the precipitation of substances by the reagents used.

The structure, as well as the mode of formation, of spherites and sphere-crystals is apparently the same. The mode of formation is, furthermore, apparently the same whether observed in nature or as carried on artificially. The different stages in their natural formation can be followed comparatively easily in those parts of plants containing hesperidin (as the epicarp of citrous fruits) or inulin (as roots of artichoke, etc.). It is interesting to compare these crystals or spherites with those formed artificially by evaporation of solutions of inulin or hesperidin. It is also instructive to compare the natural oxalates, phosphates, and carbonates of calcium with those formed artificially by precipitation of soluble calcium salts with alkaline oxalates, phosphates or carbonates.

After a comparison of the artificially produced spherites or sphere-crystals with those formed naturally in the plant, one cannot but conclude that there is a play of similar forces in their formation.

Furthermore, if we examine the crystal masses remaining in a watch-crystal after the spontaneous evaporation of solutions of various substances, under varying conditions of temperature, etc., we observe not only the formation of crystals which resemble those produced in the plant cell, but other rather striking forms of combination which are very suggestive indeed; leading one to a comparison of the arrangement of the products of crystallization with the apparent multiplicity of forms found in plant life. Indeed, the arrangement of the crystals in such a watch-crystal reminds one of the appearance of our woods in winter, when the absence of leaves permits the observance of fundamental lines of development in shrubs and trees.

If we take an alum solution (such as a Delafield's Hæmatoxylon Solution), dilute it with water and allow it to evaporate spontaneously in a watch-crystal, the result will be the formation of concentric rows of acicular crystals which show an analogy to the structure of the wheat starch-grain after treatment with the reagents mentioned.

The crystalline residue from a cocaine solution resembles a group of sclerenchyma cells in transverse section, the individual sphere-crystals resembling single cells, the portion corresponding to the wall being made up of radiating acicular crystals which even join

with those of the adjoining sphere-crystals. The latter arrangement may be likened to the pores in such thickened cell-walls.

A resemblance to the wavy contour of the walls of transverse sections of epidermal cells is exhibited in the residue formed by the evaporation of brucine solutions.

The infoldings in the parenchyma cells in pine stems and leaves is exemplified in the arrangement of the crystals which result from the evaporation of solutions of amygdalin.

From solutions of caffeine hydrobromate there separate crystals which in abundance and in arrangement resemble a dense mycelial development of penicillium with conidia.

The crystalline residue from solutions of berberine shows a marked resemblance to the outer morphology of certain *Lycopodiums*, species of *Juniper* and other similar arborescent plants. Illustrations of this kind could be multiplied which would tend to show a relationship between the form of crystalline groups and the ultimate arrangement of the substances entering into the composition of the plant.

The chemist has considered but one phase of the subject of crystallization, namely, the form and nature of individual crystals. The botanist, however, until recently has considered the aggregation of morphological units, as is evidenced in his studies on the outer and inner morphology of plants. But as the form and nature of the individual units are seen to depend more or less upon the nature of the substances comprising them, it becomes of fundamental importance to study the composition of these units in their relation to form and structure.

In the case of inorganic bodies chemical as well as physical tests are necessary to prove the identity of a substance. In the organized, or organic, world it has been impossible to define a species or designate the limitations of a species because our studies have been directed almost entirely to the outer morphology of individuals rather than to the study of the substances which, grouped together, form these individuals and the physical and chemical forces underlying their structural arrangements.

The same substance may under different conditions develop different outer forms, as, for example, alum may crystallize in monoclinic prisms, hexagonal prisms, or in arborescent forms or

sphere-crystals. Chemical tests are necessary to prove the identity of the substance in these various forms.

Not all substances, however, show this tendency to variation in form of crystals, as, for example, caffeine, berberine, and still other substances which show a tendency to uniformity in general outline.

If, then, there is so much variation in the form and arrangement of crystals of the same substance when artificially formed, to what extent may not variation in form take place in bodies of complex composition and therefore influenced by complex attractions and repulsions? Now while we see in the crystal a decided tendency to uniformity of structure under similar conditions, yet, admitting of modifications under varying conditions, we must allow that in organized structures this tendency to uniformity is modified over and over again.

In the plant world similar variations are observed, not only in forms of the elements (roots, stem, leaves, flowers, fruits and seeds) comprising the individual, but also in cell-contents. In some so-called species individuals vary greatly as regards form of elements, as in oaks, violets, etc. In others a constancy is observed, as in *Erythronium*. In still others a variation in the form assumed of some of the cell-contents is observed, as in the crystals of calcium oxalate in *Datura stramonium*,<sup>4</sup> while in other crystals a constancy of form is observed, as with calcium oxalate in the genus *Viola*. Even in the study of starch-grains one observes a constancy in the form of the grains in all plants. There is, however, a sufficient modification in some of the grains in the reserve underground parts of such plants as potato, maranta, etc., to justify one in pronouncing on the origin of the starch. The same may be said of other substances, as calcium oxalate, inulin and other carbohydrates, etc.

— The selection of certain constant forms of cell-contents or of cell-walls would appear to be of as much, or greater, importance in designating the limitations of a species as the outer form of elements, which it is evident are dependent upon the arrangement of aggregates of substances making up the individual. As this arrangement is due, on the one hand, to the chemical factors, food

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<sup>4</sup> The author, *Proc. Amer. Assoc. for Adv. of Science*, 1899; see also *Bulletin of Torrey Botanical Club*, 1899.

and air, and, on the other, to the physical factors, light and temperature, variations are bound to occur. If, however, these variations are constant for a series of successive generations and can be demonstrated in cell-contents, cell-walls and cell-functions, then a species has been formed, but not otherwise.

In the inorganic world, as we well know, physical and chemical tests both are oftentimes necessary to prove the identity or specific nature of a substance. Likewise in the biological world physical and chemical tests of cell-contents, cell-walls and the products of cell-function are necessary to establish the specific character of an individual.

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